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ENHANCING RELIABILITY OF DISTRIBUTION LINES THROUGH ENGINEERING ASSESSMENT OF STRENGTH AND GALLOPING

Report No. 90-101-K

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ABSTRACT

An engineering assessment of a 44 kV subtransmission line near Kincardine, with a history of weather related service outages, has led to specific recommendations for additions of guys and galloping controls. The procedure followed can be applied to any distribution line and offers a direct approach to improved reliability.

job	file	date	report no.
21-302-031	825.151	May 25, 1990	90-101-K

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EXECUTIVE SUMMARY

ENHANCING RELIABILITY OF DISTRIBUTION LINES THROUGH ENGINEERING ASSESSMENT OF STRENGTH AND GALLOPING

D.G. Havard and A.H. Jubb

A 44kV line to Kincardine, in Georgian Bay Region, has had a history of unsatisfactory reliability leading to complaints from the local municipality to Ontario Hydro. An independent engineering assessment of the line was carried out at the request of the Region. This involved an evaluation of the weather conditions, the strength of the poles and the conductor clearances. The line contains single and double circuit wood crossarm construction and some double circuit armless construction. Previous field experience of galloping of distribution lines with and without control devices was reviewed and related to the parameters of the line. This indicated that galloping can be expected to cause outages in many sections of the line. Increasing clearances or use of control devices can reduce these outages to an acceptable level. Specific recommendations for additional guying and for application of galloping controls are included. The degree to which the recommendations were applied by the Region and the effect of the changes on the line's reliability are discussed.

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To Dr. D. Mills
Director of Research

ENHANCING RELIABILITY OF DISTRIBUTION LINES THROUGH ENGINEERING ASSESSMENT OF STRENGTH AND GALLOPING

D.G. Havard and A.H. Jubb

1.0 INTRODUCTION

The town of Kincardine and nearby districts in Walkerton Area, Georgian Bay Region, were exposed to frequent and lengthy outages in recent years as a result of various problems on the 95M4/M6 44 kV feeders from Douglas Pt. TS. To address this unsatisfactory level of reliability, Georgian Bay Region requested the Distribution Planning & Design Department (now Retail Delivery Systems Department to conduct an independent engineering assessment of these 2 feeders. Since a significant number of the outages were thought to be caused by galloping conductors, D. Havard of Research Division was invited to participate in the assessment.

On June 4, 1987 D. Havard (Research) and H. Jubb (Retail Delivery Systems) met with E. Rousseau (Georgian Bay Region), to define the nature and scope of the assessment of the 95M4/M6 feeders. Since a complete electrical and mechanical assessment of the 35 km of line would be time consuming and costly, it was decided to audit representative selected line sections. Furthermore, after reviewing the nature of the outages, it was agreed to confine the audit to pole strength, including guys, and susceptibility to galloping induced interruptions.

1.1 Line Description

The 95M4/M6 feeders share a single pole line for approximately 24 km from Douglas Pt. TS to Bruce St. Jct on the outskirts of Kincardine as shown in Figure 1. The M6 continues south of Bruce St. Jct. to Reid Corner DS approximately 11 km. The double circuit portion of the line is mainly crossarm construction (diamond configuration) although approximately 6 km is armless construction. Primary underbuild is present on most of the line. However, there is no primary underbuild in the two cross country portions of the line. Typical pole top framings are shown in Figure 2.

In general, the line consists of long straight sections with 8 corners and several road crossings. The terrain varies from flat to slightly rolling. Almost all the surrounding land is agricultural. As a result, the line is mainly exposed but trees and bushlots provide protection in some locations. The line runs roughly parallel to the Lake Huron shoreline.

1.2 Meteorological Environment

The nearest weather stations to the Kincardine location are at Southampton, which is no longer functional, and Mount Forest. The historical wind data from Southampton and the wind and ice data from Mount Forest have been summarized as part of an analysis of Ontario weather by Gorski[1].

The summary shows that the area has:

(1) no predominant wind direction in the winter months,
(2) lower than average maximum wind speeds, (61 km/hr n Southampton and 72 km/hr in Mount Forest compared to 97 km/hr in Toronto and 100 km/hr in London.)
(3) the longest duration of freezing precipitation, (68.0 hr in Mount Forest compared to 37.2 hr in Toronto and 48.6 in London.)
(4) median levels of accumulated ice accretion,
(5) median levels of combined ice and wind loads.

Consequently all sections of the 95M4/M6 feeders being studied have higher than normal exposure to combined modest ice and wind loads, which is the combination most often found to lead to galloping.

2.0 DATA ACQUISITION

On July 8, 9 and 10, 1987, E. Rousseau, D. Havard and H. Jubb visited the site of the 95M4/M6 feeders. Thirteen spans, representing various framings, locations and exposures were selected for analysis. Various line parameters were observed and noted. Subsequently, the Walkerton Area staff recorded additional measurements in these spans. The specific measurements and other line details documented are identified in the working sheets, samples of which are included in Appendix C. These working sheets were the basis for the subsequent engineering assessment.

3.0 ANALYSIS

The engineering assessment focussed on analysis of four key aspects of the 95M4/M6 feeders:

(a) Pole Top Framings
(b) Pole Strength
(c) Storm Guys
(d) Galloping Clearances

Details of the analysis are given in Appendix A.

4.0 ASSESSMENT FINDINGS AND RECOMMENDATIONS

Following analysis of the collected data, an interim report was prepared and submitted to Georgian Bay Region. A copy is included in Appendix B. The interim report included a summary of the main findings and a set of recommendations for reinforcing the strength of the 95M4/M6 line and reducing its susceptibility to galloping induced outages. Georgian Bay Region then used these recommendations as a basis for modifications to the line to improve the reliability of these feeders.

4.1 Work Undertaken

In 1988 Walkerton Area initiated some of the rehabilitation work recommended in the interim report to improve reliability. In particular, the following work has been carried out to date:

(a) Installed 19 additional storm guys to meet, and in some cases, exceed the requirements of the Distribution Standards - Lines.

(b) Reframed poles to increase conductor spacings. This work was abandoned after reframing several poles due to the time and cost incurred.

(c) Installed approximately 100 galloping control devices (air flow spoilers) on the centre phase only of the east/west sections of the line. In all cases control devices were installed on the road side circuit. In some cases control devices were also installed on the field side circuit.

The area is continuing to install storm guys and control devices as time and resources permit. The approximate cost of the work done to date is summarized as follows:

Storm guys:	$35,000
Reframing	$22,000
Air flow spoilers	$37,000
Total	$94,000

4.2 Impact on Reliability

Prior to the commencement of this assessment, Georgian Bay Region had compiled the following reliability data for the five year period of April 1982 to April 1987:

	95M4	95M6
Outage time	5.65 hr/yr	6.13 hr/yr
No. of outages	4.0/yr	4.4/yr

Similar data for 1988 and the first quarter of 1989 were compiled from information provided by Georgian Bay Region.

	95M4	95M6
Outage time	0.02 hr/yr	0.00 hr/yr
No. of outages	0.8/yr	0.0/yr

Although these figures suggest that a significant improvement in reliability has occurred, it is too early to conclude whether this is due to the remedial work carried out on the 95M4/M6 feeders. The improvement may be due, at least partially, to less severe weather conditions.

5.0 CONCLUSIONS

1. An engineering assessment was carried out which identified causes of the unsatisfactory reliability of the 95M4/M6 feeders and provided recommendations for improvement.

2. The recommendations of this engineering assessment provided a basis for including modifications to the line into the Walkerton Area's business and maintenance plans and to phase the work in a manageable manner.

3. There has been a significant improvement in reliability and service to the customer, Kincardine PUC. However, several more years of outage data are required before it can be concluded to what extent this improvement is due to the remedial work carried out on the 95M4/M6 feeders.

4. The methodology used is applicable to other distribution lines with unsatisfactory reliability records.

6.0 ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of a number of Ontario Hydro staff who contributed to this study. In particular we wish to recognize Mr Ed Rousseau of Georgian Bay Region and the staff of Walkerton Area who carried out the detailed measurements of the spans selected for study.

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2. *"Performance of Galloping Control Devices on Ontario Hydro Lines: 1981-1982 Winter"*, Research Division Report B82-52-K, File 825.151 by C.J. Pon.

3. *"Analysis of Conductor Galloping Field Observations - Single Conductors"*, Trans IEEE Vol PAS-100, No 8, Aug 1981, pp 3744-53, by C.B. Rawlins.

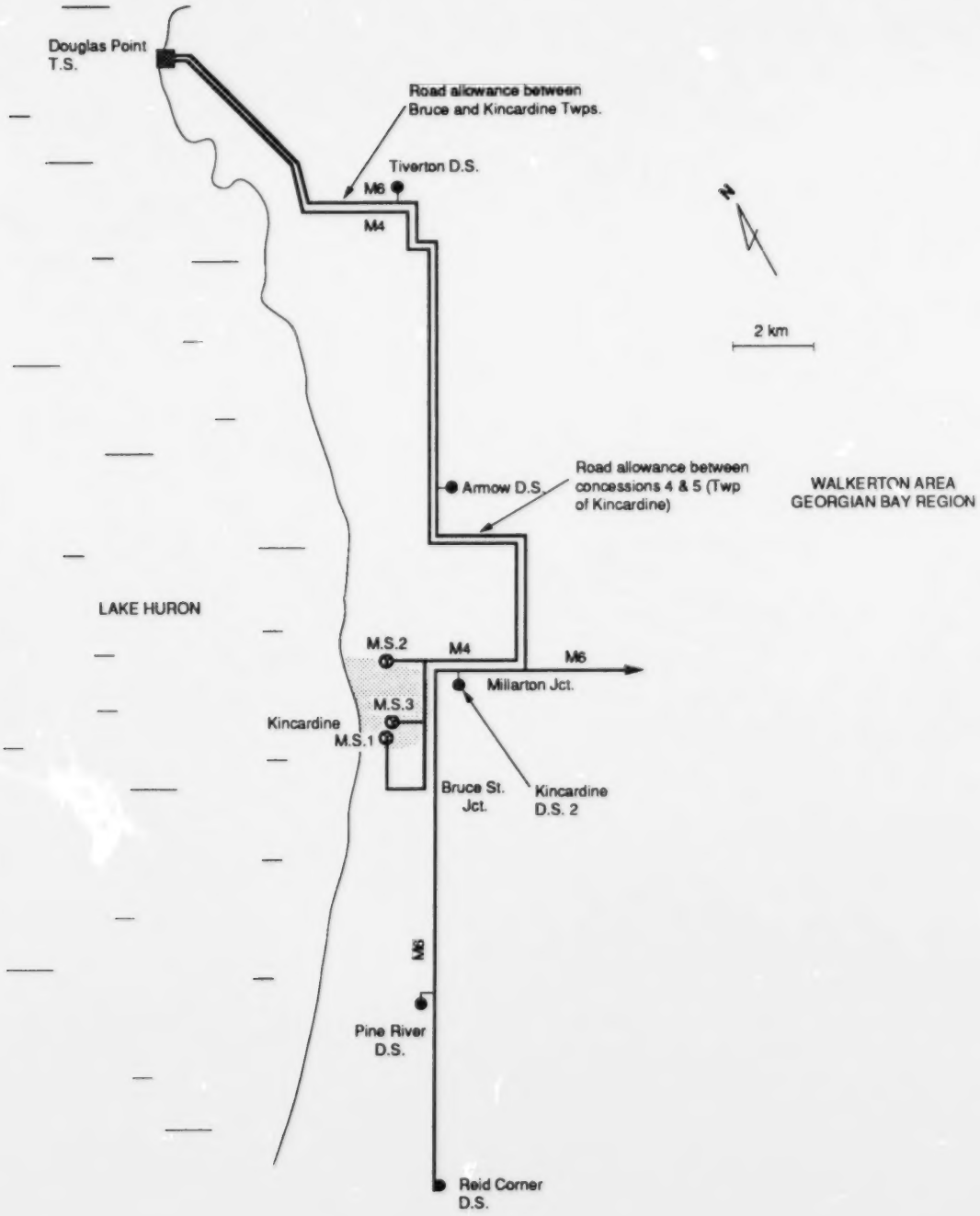
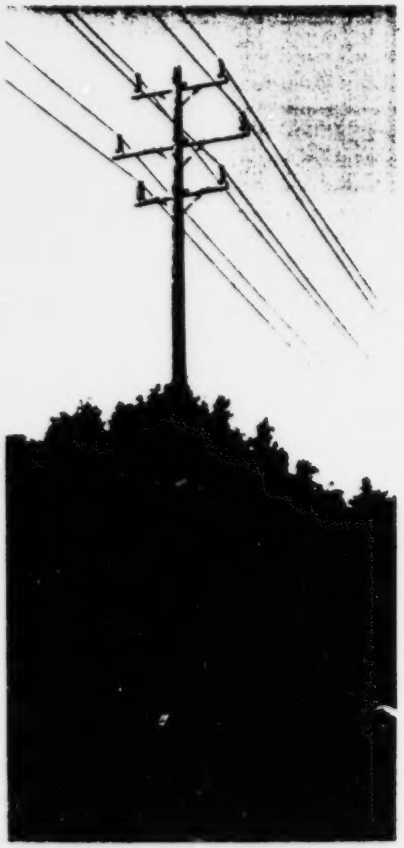


FIGURE 1

**ROUTE OF DOUGLAS POINT T.S. 95M4/M6 44 kV
FEEDERS TO KINCARDINE**



(a)

(b)

(c)

FIGURE 2

DISTRIBUTION LINE POLE TOP FRAMINGS

(a) Double Circuit 44 kV Wood Crossarm Construction

(b) Single Circuit 44 kV Wood Crossarm Construction with underbuilt rural circuit

(c) Double Circuit 44 kV Armless Construction with underbuilt rural circuit

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APPENDIX A

ANALYSIS

A.1 Pole Top Framings

Seven different framing arrangements were identified in the 13 selected spans. These are detailed in Table A1. Each was compared to the Distribution Standards-Lines with respect to dimensions and arrangement of components.

Six of the framing arrangements were consistent with those in the Distribution Standard-Lines, although there was some minor variation in vertical dimensions. The seventh framing (single circuit 44 kV) varied from the Distribution Standards-Lines with respect to the length and location of the crossarm. However this is considered to be an acceptable arrangement.

A.2 Pole Strength

The adequacy of pole strength (class) was determined by comparison to the requirements of the current Distribution Standards - Lines (ED5-27, August, 1986). In addition to the pole classes observed and recorded in the 13 selected spans, line data records specifying pole class, span length and framing, were available for the entire Douglas Point TS to Millarton Jct. portion of the line. Using this data, the classes of most of the poles in the line were compared to those recommended by the Distribution Standards-Lines. These comparisons appear in Table A1. Approximately 25% of the poles are weaker than required.

On Feb. 8, 1987 seven poles in the Douglas Pt. TS to Millarton Jct. portion of the line failed on the road allowance between concessions 4 and 5, Township of Kincardine. Using the line data records and current Distribution Standards - Lines it was found that only two of the seven poles were weaker than required. However, in these two cases, the span lengths were only 1 m and 2 m longer than recommended for the actual pole class. This suggests that the 7 failed poles were exposed to loadings greater than those assumed for design purposes by the Distribution Standards-Lines. However, to our knowledge these are the only poles to have failed in this line due to weather conditions since construction. Therefore the loadings assumed in the Distribution Standards - Lines appear to be generally suitable for the 95M4/M6 line.

A.3 Storm Guys

In the Douglas Pt. TS to Millarton Jct. section of the line storm guys appear to be present in all locations specified on the original roll plans for this line. Some additional storm guys have been added along the road allowance between Bruce and Kincardine Township. Unfortunately, the new storm guys are only on the south side of the road, presumably due to the difficulty of obtaining permission to install anchors in the agricultural land on the north side.

For the type of framings on this line, the Distribution Standards - Lines suggest that storm guys be installed at 5 span intervals . Between Douglas Pt. TS and Millarton Jct. there are approximately 22 sections of line with 6 or more consecutive spans unguyed to the left and 17 sections of 6 or more consecutive spans unguyed to the right. Furthermore, 6 of these line sections have 10 or more consecutive spans unguyed to the left and 4 have 10 or more consecutive spans unguyed to the right. In one of these cases there are 27 consecutive spans unguyed to the left.

The balance of the line (west and south of Millarton Jct.) was not analyzed due to the lack of field observations, roll plans and line data records.

A.4 Galloping

A.4.1 *Poletop Clearances*

For each conductor, galloping is assumed to take place within an elliptical envelope which is approximately vertical and its height is three times its width. These ellipses can be related to the poletop geometry to determine the likelihood of flashovers between conductors. The galloping clearance ellipses are separated by an air gap corresponding the voltage of the line. An air gap of .13 m is required between the ellipses to avoid flashovers at 44 kV. Figure A3 includes the maximum ellipse heights that can be accommodated by the various poletop geometries along the line. A chart to permit the available ellipse heights to be conveniently estimated for most poletop arrangements is provided in Figure A4.

A.4.2 *Galloping Background*

Field studies of galloping distribution lines in Ontario Hydro and elsewhere have led to a substantial data base of observations. The maximum motions recorded in Ontario are 2.65 m peak to peak in the vertical plane[2]. While this is a rare event, it is probable that such motions occur unseen somewhere in the distribution system during most winters. A study of similar events based on a survey of a large group of US utilities[3] has produced a method of estimating maximum galloping amplitudes on distribution lines. The amplitude depends on key line parameters such as span length, conductor size and tension, and details of the support hardware at the pole. For the Kincardine lines the approach predicts maximum amplitudes between 1.7 and 2.7 m. These predictions are included in Figure A3 for each representative span studied.

A.4.3 *Probability of Flashover*

Figure A3 can be used to compare the expected maximum galloping amplitude and the space available to accommodate the galloping motions. This can be used to rank the sections of the line according to likelihood of flashover. The figure shows that all sites have insufficient clearance for phase to rural galloping. All sites, except the single phase horizontal arrangements, are also deficient for phase to phase galloping. Sites 4, 5 and 12, which are the armless construction, have the least clearance.

A.4.4 *Galloping Control Devices*

Application of galloping controls, such as detuning pendulums and air flow spoilers, Figure A1, can reduce the galloping motions. Smaller clearances are then required within the poletop to prevent flashovers. The amount of reduction can be determined from a study of the field observation data. Figure A2 shows the data obtained from 42 occurrences of galloping on distribution lines with no controls, with detuning pendulums and with air flow spoilers. The data in the figure are scaled by dividing all peak to peak motions by the maximum motion predicted using the Rawlins' method[3]. This allows direct comparison between different conductor sizes and span lengths. The resulting graph shows that without control devices a maximum scaled amplitude of 0.80 is reached once per 1000 spans in each ice storm. With detuning pendulums and air flow spoilers installed the equivalent projected maximum normalized amplitudes are 0.52 and 0.34. For typical spans in the 95M4/M6 line these correspond to peak to peak amplitudes of 2.1, 1.4 and 0.9 m, respectively. Due to scatter in the

results the accuracy of the above amplitude predictions is about 15%. These amplitudes are estimated to correspond to the maximum amplitude expected on this line during two ice storms and would results in one flashover in that period.

It should be noted that the detuning pendulums will required additional clearance to accommodate their length making the required ellipse size 1.7 m. This means that some poletop framings do not have sufficient clearance without further modifications to permit pendulums to be used. The clearance required for the air flow spoilers already exists in all poletop framings in the line. On this basis the air flow spoilers are the preferred add-on control device for this line. For the span lengths involved four are required per span. The maximum benefit is obtained by treating all phases. For some framings only the middle phase, and others only the top and bottom phases, need to be treated.

A.4.5 *Framing Changes*

As an alternative to adding galloping controls, increasing the clearance within the existing framing was reviewed. The greatest benefit can be obtained by increasing the horizontal offset between the middle and the other phases. For example at site 1, with wooden crossarms having a 1.23 m vertical and 0.9 m horizontal spacing, a 2.65 m high ellipse can be accommodated. On the other hand at site 4, with armless construction and a 1.31 m vertical and no horizontal separation, the ellipse that can be accommodated is only 1.19 m high. There were some sites in this line where changes of horizontal conductor position were possible and offered sufficient increase in ellipse size to significantly decrease the probable flashover rate. However after a few trials such changes were found to be very labour intensive. This approach was dropped in favour of adding the air flow spoiler galloping control devices.

TABLE A1

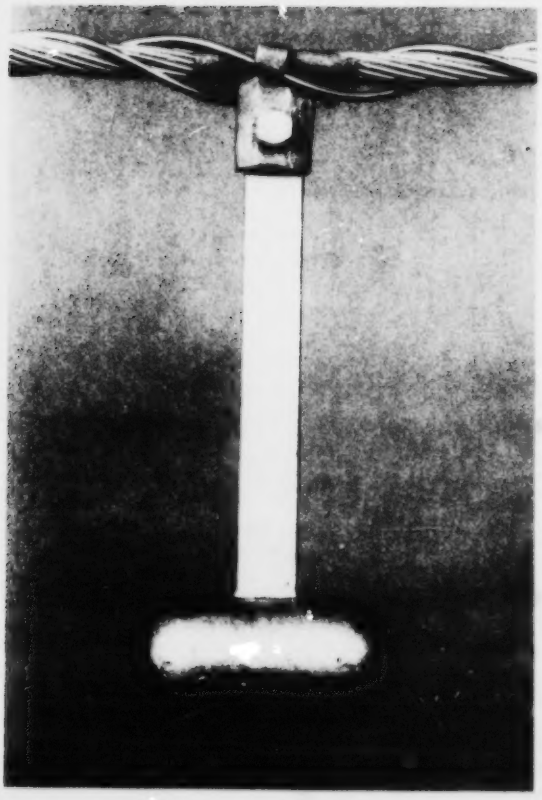
POLE CLASS ANALYSIS

FRAMING DESCRIPTION	AUDIT SITE	OBSERVED POLE CLASS (NOTE 2)	MEASURED SPAN LENGTH (m)	CONDUCTORS	POLES REPRESENTED	DISTRIBUTION STANDARDS		REPRESENTED POLES UNDER STRENGTH
						POLE CLASS	MAX SPAN	
1 cct 44kV crossarm 3ϕ primary crossarm	1 2 3	4/? 4/? 4/4	77 84 86	44kV 1/0 ACSR Primary 3/0 ACSR Neutral 1/0 ACSR	approx. 165	5 4 3	76 98 110	Note 1
2 cct 44kV armless 3ϕ primary armless	4 5	1/1 2/2	67 55	44kV 556.5 Alum. Primary 3/0 ACSR Neutral 1/0 ACSR	approx. 95	4 3 2	53 69 85	Note 1
2 cct 44kV crossarm 1ϕ primary crossarm	6	4/4	69	44kV 336.4 Alum. Primary 3/0 ACSR Neutral 1/0 ACSR	23	4 3	67 85	7
2 cct 44kV crossarm (no primary)	7 13	4/4 3/4	70 69	44kV 336.4 Alum.	119	4 3	79 105	0
2 cct 44kV armless 1ϕ primary crossarm	8	2/2	65	44kV 336.4 Alum. Primary 3/0 ACSR Neutral 1/0 ACSR	7	4 3	67 85	0
2 cct 44kV crossarm 3ϕ primary crossarm	9 10 11	?/4 3/2 3/3	52 63 68	44kV 336.4 Alum. Primary 3/0 ACSR Neutral 1/0 ACSR	146	4 3 2	61 78 99	63
2 cct 44kV armless 3ϕ primary crossarm	12	3/3	54	44kV 336.4 Alum. Primary 3/0 ACSR Neutral 1/0 ACSR	24	4 3 2	61 78 99	14

Notes: 1) Pole class for represented poles not available from line data records.

2) The pole class for both poles in each selected span is given; "?" indicates pole class could not be identified.

A. Air Flow Spoiler



B. Detuning Pendulum

FIGURE A1

GALLOPING CONTROL HARDWARE FOR DISTRIBUTION LINES

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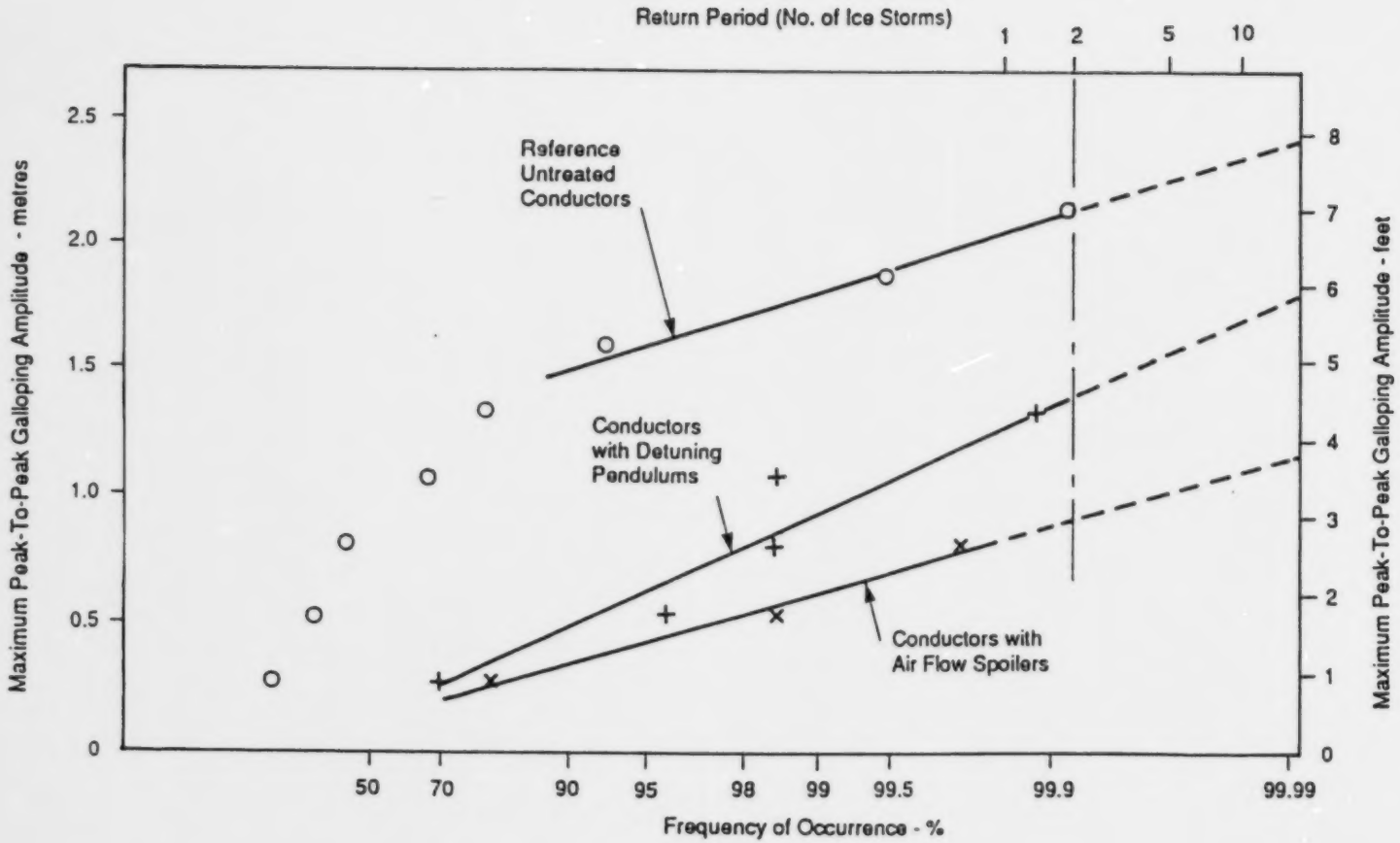
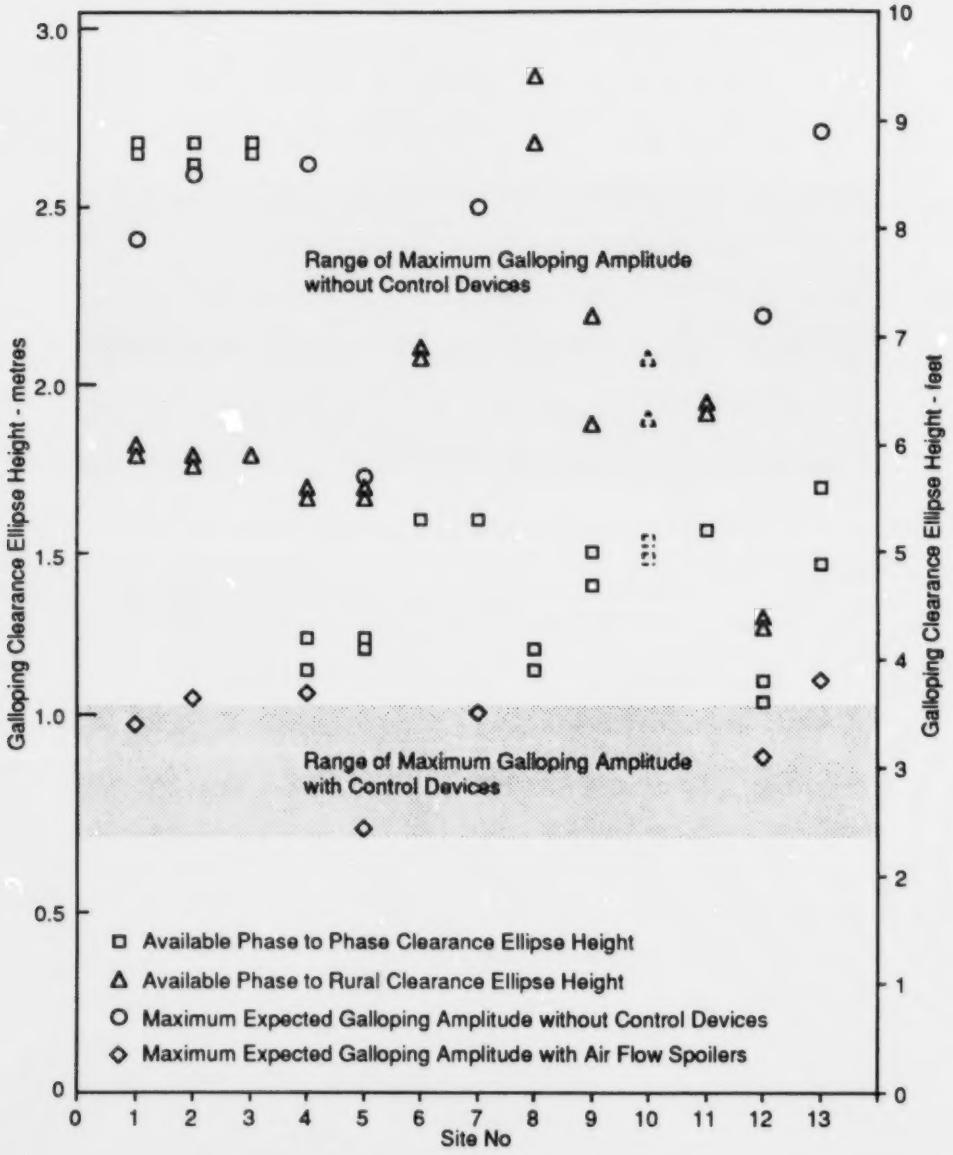


FIGURE A2

GALLOPING AMPLITUDE VS FREQUENCY OF OCCURRENCE FOR DISTRIBUTION LINES WITHOUT CONTROLS, WITH DETUNING PENDULUMS AND WITH AIR FLOW SPOILERS

NOTE: VALUES ARE FOR A 250 ft. SPAN WITH A SAG OF 4 ft.


Galloping Clearance Ellipse Height - metres
Galloping Clearance Ellipse Height - feet
Site No
Range of Maximum Galloping Amplitude without Control Devices
Range of Maximum Galloping Amplitude with Control Devices
Available Phase to Phase Clearance Ellipse Height
Available Phase to Rural Clearance Ellipse Height
Maximum Expected Galloping Amplitude without Control Devices
Maximum Expected Galloping Amplitude with Air Flow Spoilers

NOTE: Maximum expected galloping amplitude without control devices at sites 3, 6, 8, 9, 10 and 11 were not able to be calculated due to missing data

FIGURE A3

COMPARISON OF AVAILABLE CLEARANCE ELLIPSE HEIGHT WITH MAXIMUM EXPECTED GALLOPING AMPLITUDES ALONG THE LINE

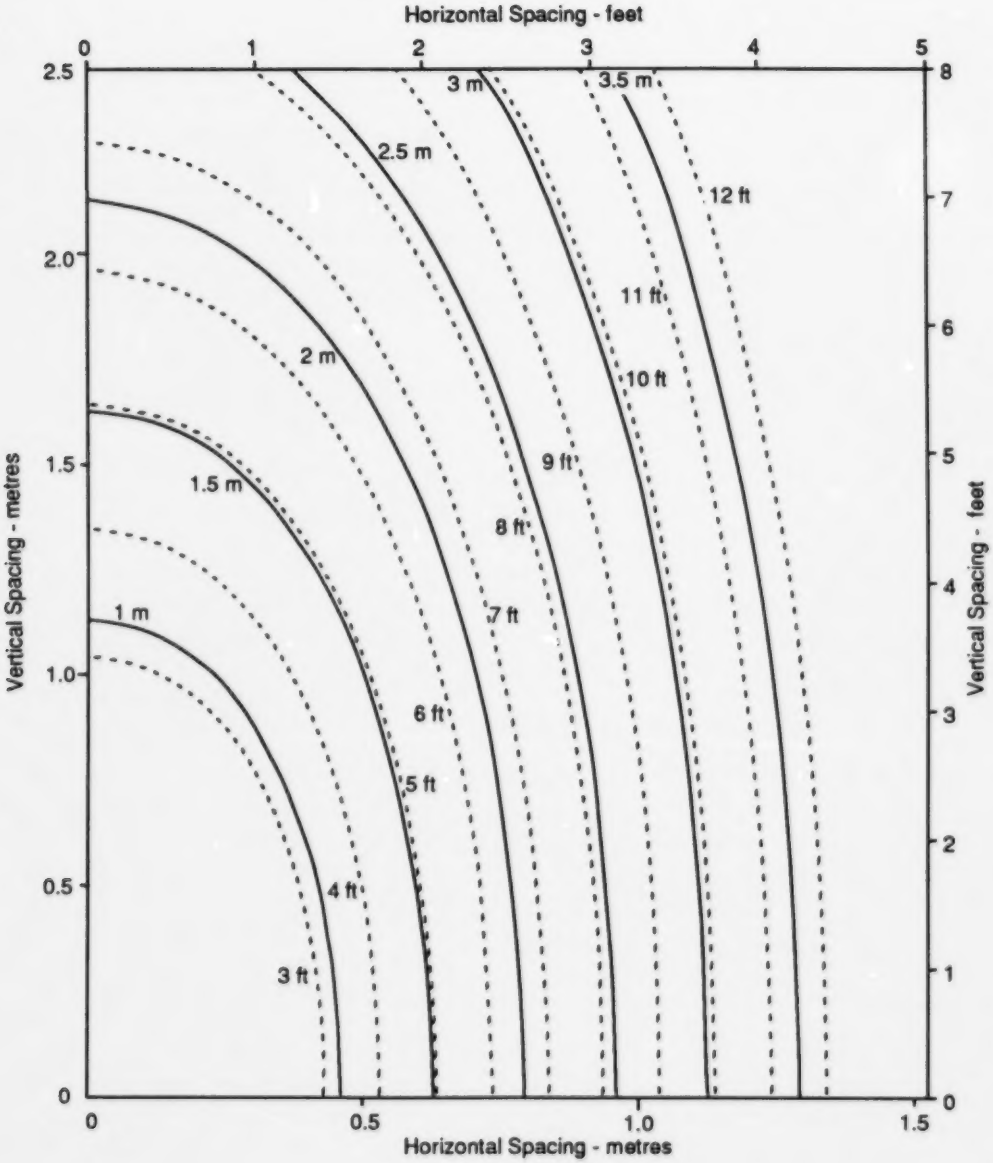


FIGURE A4

GALLOPING ELLIPSE SIZES ACCOMMODATED WITHIN POLE TOP FRAMING
AIR GAP = 5 INCHES (0.13 m)

APPENDIX B

ENGINEERING ASSESSMENT OF 44kV FEEDERS

DOUGLAS POINT TS TO KINCARDINE PUC

Interim Report

1.0 Findings

1.1 Single and double circuit pole framing arrangements are generally consistent with Distribution Standards - Lines.

1.2 Approximately 25% of poles in the Douglas Point TS to Millarton Jct. portion of the line are of a weaker class than required by current Distribution Standards - Lines. In most cases, these poles are exposed to wind spans approximately 10% longer than specified in the Distribution Standards - Lines.

1.3 In the Douglas Pt. TS to Millarton Jct. portion of the line, there are approximately 22 sections of line with 6 or more spans unguyed to the left (as viewed from Douglas Pt. TS) and approximately 17 sections of line with 6 or more spans unguyed to the right. In 10 of these line sections, there are 10 or more spans unguyed in one or the other direction.

1.4 Meteorological data from the nearest weather stations (Mount Forest and Southampton) indicate:

a) Maximum mean wind speeds are significantly lower than those of Toronto and London.
b) There is no significant prevailing wind direction in the winter months.
c) Annual hours of freezing precipitation are probably the maximum in the province.
d) Estimated ice accretion is near the provincial median.
e) Estimated combined wind and ice loadings are also near the provincial median.

1.5 Predicted peak-to-peak galloping amplitudes on this line are approximately 6 to 9 feet depending on span length, sag, etc.

1.6 The ranking of pole framings in worst to best order for probability of galloping induced flashovers is as follows:

a) double circuit armless
b) double circuit crossarm (exposed)
c) double circuit crossarm (sheltered)
d) single circuit crossarm.

2.0 Recommendations

2.1 Consider pole replacement in the few locations where the wind span is more than 10% longer than that specified in current Distribution Standards - Lines. Alternatively, install reinforcing guys in these locations.

2.2 Install storm guys to reduce the number of unguyed spans in any exposed section of line to 5.

2.3 To reduce flashovers due to galloping to approximately one (over the entire length of this line) for every two ice storms (on average), consider the following action:

a) Sheltered spans (poles 1 to 86 and 131 to 151): no action

b) Single circuit 44 kV crossarm framed poles: no action

c) Double circuit 44 kV crossarm framed poles:

Relocate insulators on top and bottom crossarms to approximately 2 feet from the pole

or

Install galloping control devices (air flow spoilers) on both centre phases (4 spoilers per phase per span)

d) Double circuit 44 kV armless framed poles:

Replace centre phase insulator stand-off brackets with a 43A crossarm

or

Install galloping control devices (air flow spoilers) on all phases (4 spoilers per phase per span)

H. Jubb
Distribution Planning & Design

D.G. Havard
Mechanical Research

September, 1987

APPENDIX C - LINE DATA WORK SHEETS

DOUGLAS PT - MILLARTON JCT

STRUCTURE DATA

NAME: D.G. Havard DATE: 8 July 87

SITE 4, PHOTO 6

POLE NO.: 1N of Bruce, 2N of Bruce		CONDITION: Good, Good	
HEIGHT: 60, 60	CLASS: 1, 1		DIAMETER: 58"/π, 58"/π
DATE NAIL: 78, 78			
SETTING DEPTH:* 2', 1'5"		FOUNDATION: Class 1, Class 1	
FRAMING: a) 44 kV: ED 7-252			Double cct armless
b) Primary: 3ϕ armless			
c) Other:			
DIMENSIONS: a) 44 kV: to be measured			
b) Primary: to be measured			
c) Other:			
INSULATION: Post insulators with clamps			
FRAMING STIFFNESS:			
GUYING: Yes, Yes (tie to service)			
STORM GUYING:			
MISCELLANEOUS:			

* Measurement between date nail and grade.

DOUGLAS PT - MILLARTON JCT

IN-SPAN DATA

NAME: D.G. Havard DATE: 8 July 87

SITE 4, PHOTO 6

ADJACENT POLE NOS.:	1 and 2 N of Bruce St.	
LENGTH:	221 ft.	
SAG:	To be measured	
CONDUCTOR SIZE & TYPE:	a) 44 kV:	556 kcmil aluminum
	b) Primary:	3/0, Neutral 1/0 ACSR
	c) Other:	
BURN MARKS:		
EXPOSURE:	Flat	
MISCELLANEOUS:		